Studies on transfer factors and transfer coefficients of Cesium and Strontium in soil-grass-milk pathway and estimation of radiation dose in the environment of Kaiga

Synopsis of the Thesis to be Submitted to the Mangalore University for the Award of the Degree of Doctor of Philosophy in Physics

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STUDIES ON
TRANSFER FACTORS AND TRANSFER COEFFICIENTS OF CESIUM AND STRONTIUM IN SOIL-GRASS-MILK PATHWAY AND ESTIMATION OF RADIATION DOSE IN THE ENVIRONMENT OF KAIGA

1.0 Introduction

Four PHWR type nuclear reactors each of 220 MWe power have become operational at Kaiga, about 60 km from the west coast town of Karwar, India. During the operation of the nuclear power reactors, the release of radionuclides to the environment is strictly controlled. The meticulous monitoring ensures that the rate of release is well below the internationally and nationally permissible limits so that the radiological impact to the members of public is kept as low as possible. Sufficient engineering safety features are incorporated in the design of the nuclear power reactors to avoid the possibility of any accidents involving the release of radionuclides to the environment. In spite of these, it is important that detailed studies on radioecology are carried out on regular basis in the environment of nuclear power reactor during its normal operation.

In case of any accidents radionuclides released from the nuclear facilities get dispersed in atmosphere and hydrosphere of local environment and may reach the members of public through (i) deposition on grass and subsequent transfer to cow and milk, (ii) direct deposition on vegetables or crops, and (iii) deposition on agriculture land – which results in the uptake of radioactivity by the crops grown over it.

Cesium and Strontium are regarded as important radionuclides as they are environmentally mobile and transfer readily to foodstuffs. The ^{137}Cs has long half life of 30.2 years and becomes actively included in food chains and uniformly distributed throughout organs and tissues like alkali elements – K, Na, and Rb. The ^{90}Sr ($T_{/2}$=29.3 years) has an exceptional capacity for being included in the metabolism of plants, animals and man and selectively concentrates in bone like other alkaline-earth elements – Ca, Ba,

Ra. The isotopes of Cesium (^{137}Cs and ^{134}Cs) and strontium (^{90}Sr) are important radionuclide as it may be transferred to cow milk, leading to significant dose to those consuming milk, especially infant and children. This is because these radioisotopes released to the environment are intercepted by plant surfaces that are then grazed by dairy cows. Alternatively these radioisotopes can also be taken up by plants though the root.

2.0 Environmental transfer factors and their importances

The radiological impact of routine releases of radionuclides from nuclear facilities is usually evaluated using mathematical models. In such models the pathways of radionuclides from the release point to humans are described by transfers between compartments, e.g; the transfer of airborne radionuclides through the compartments 'air' and 'pasture' to 'milk'. The radionuclide transfer between compartments is commonly described by transfer parameters. In simple models these transfer parameters represent the ratio of concentrations of a radionuclide in two compartments under equilibrium conditions. In order to determine the radiological impact of releases, it is essential to understand the processes and pathways through which the radioactive materials reach the population around the nuclear power plant. Thus the assessment of dose from these pathways can be done from the knowledge of concentration of different radionuclides in different environmental matrices and the transfer factors. Therefore evaluation of transfer factors for natural and stable elements in various food chains is essential to assess long-term radiological hazard to the population of the region. It is recognised in the worldwide that to make reliable assessment of doses through the ingestion pathway, there is a need for extensive empirical data on transfer factors for different types of food consumed by the population around the nuclear facility.

3.0 Significance of studies on environmental transfer factors and transfer coefficients for Kaiga region

Though extensive studies on the distribution and transfer mechanism of iodine, cesium and strontium in different environmental compartments and the resulting radiation

dose to the human have been carried out in developed countries, these studies are no means complete. It is recognised that general assessment calculations that are used to predict the environmental transport and ensuing doses resulting from the release of radioactive substances involve uncertainties due to the lack of site-specific information.

It is very well known that the atmospheric dispersion of radioactive substances is dependent largely upon the local environmental parameters such as humidity, temperature, pressure, rainfall, wind direction and speed, etc. At specific sites especially when local topographic features affect the meteorological conditions, the parameters influencing the dispersion and movement of the radionuclides in the environment vary considerably from the regional average. For example, mountains lining a river valley can influence the local weather pattern such that it differs significantly form that considered typical for the surrounding region. The density of vegetation cover also largely influences the dispersion of radioactive materials. Each site situation, therefore, may lead to very different values for the dispersion factors of radionuclides released into the environment[1]. Similar effects can occur near large bodies of water, where the differences in land and water surface temperatures are often large enough to create air circulation that favours certain directions.

Kaiga is a humid region with annual average rainfall above 3500 mm. Landscape of Kaiga is also unique, with the Kaiga Generating Station is surrounded by mountains and dense ever green deciduous forest comprising of hundreds of different vegetation species, belonging to different taxonomic groups. The dry precipitation rate is also high in this region. The earlier studies[2,3,4] on the distribution of natural and artificial

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1. Handge P. and Hofman F. O. The necessity for environmental surveillance in the evaluation of nuclear power plant sites. IAEA-SM-180/20.

2. Karunakara N, Avadhani D N, Mahesh H M, Somashekarappa H M, Narayana Y and Siddappa K. ^{137}Cs Concentration in Environment of Kaiga in the south West Coast of India, *Health Physics*, USA, Vol. 81, No 2, pp 148-155, 2001.

3. Karunakara N, Avadhani D N, Mahesh H M, Somashekarappa H M, Narayana Y and Siddappa K. Distribution and enrichment of ^{210}Po in the environment of Kaiga in south India, *Journal of Environmental Radioactivity*, UK, 51, pp. 349-362, 2000.

radionuclides have shown the presence of significantly higher concentrations of ^{137}Cs, ^{210}Pb, ^{210}Po and ^{7}Be in soils and vegetation of Kaiga region. A comparison of the concentrations of these radionuclides observed in Kaiga region with those reported for other parts of the country show that the concentration of these radionuclides in Kaiga region is significantly higher. These studies have also shown that the higher activities of ^{137}Cs, ^{210}Pb, ^{210}Po and ^{7}Be are because of the special topographical features of Kaiga, which act like a trapping bowl for aerosols and fallout radionuclides.

It is clear from the above discussion that because of the unique features of Kaiga site it is very important that detailed studies on transfer factors for Cesium and Strontium in pathway involving cow milk in the environment of nuclear installation situated in a unique topographical region to generate the database, which will be specific for Kaiga region. Such studies are useful under all circumstances for anticipating the environmental accumulation of long-lived isotopes that might results with the future growth of the nuclear industry. The information that would be obtained from this programme would enable more realistic values to be derived for use in general assessment calculations. The data generated from this study will prove valuable as early-warning indicators and will play a crucial role during the assessment of situations where restrictive guideline values might be exceeded due to an accidental or short-term excessive release of radioactivity.

4.0 Aims and objectives of the study

The main objectives of the study are,

i. To analyze the radionuclide and stable isotopes (^{137}Cs, ^{40}K, stable Cesium, Potassium, Strontium and Calcium) concentrations in soil, grass and milk around Kaiga region,

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[4]. Karunakara N, Avadhani D N, Mahesh H M, Somashekarappa H M, Narayana Y and Siddappa K. ^{226}Ra, ^{40}K and ^{7}Be activity concentration in plants in the environment of Kaiga, India. , *Journal of Environmental Radioactivity*, UK, 65, pp. 255-266, 2003

ii. To estimate the soil to grass transfer factors (F_v) and grass to milk transfer coefficients (F_m) for Cesium and Strontium (stable and radioactive isotopes) for normal operation conditions of nuclear power plant as well as for the emergency situations,

iii. To generate a data base on dietary pattern of general population of Kaiga region, which is essential for dose estimation, through a well planned demographic survey, and

iv. To estimate the ingestion dose due to Cesium and Strontium radioisotopes to children and adults through pathway involving cow milk for normal and emergency situation.

5.0 Overview of the work done

To start with, a detailed protocol[5] incorporating the procedure for sample collection, sample processing, frequency of sampling and analytical methods for determination of site-specific parameters etc. were formulated for the studies in consultation with the scientific staff of Environmental Survey Laboratory (ESL), Kaiga and Bhaba Atomic Research Centre (BARC), Mumbai. An experimental grass field of size 30 m × 20 m was developed at Kuchegar, a village near the nuclear power plant in Kaiga for studying the soil to grass transfer factors. For evaluating the site-specific transfer coefficients for ^{137}Cs and ^{90}Sr for the 'soil-grass' system, soil and grass samples were collected regularly following standard procedure. Two local breed cows were adopted for the present study and these cows were allowed to graze normally in the experimental grass field. Necessary permission was obtained from the university animal ethics committee to adopt cows for the study. Milk samples from these adopted cows were collected on daily basis to evaluate equilibrium transfer factors for radionuclides and stable elements.

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5. BARC report, Standard protocol for evaluation of environmental transfer factors around NPP sites', BARC/2008/E/023.

For comparative study, soil and grass samples were also collected from many common grazing areas of Kiaga region and analyzed. Milk samples from cows of local farmers which graze in these common grazing areas were also collected and analyzed. Dairy farms are the important milk sources available for locals in Kaiga and hence it could be an important contributor to radiation dose to public through ingestion of radionuclides in the case of emergency. In view of this, samples of soil, grass, feed and milk from a dairy farm located in 20 km zone of nuclear power plant were also collected and analyzed in the present study and transfer factors and transfer coefficients were estimated.

The transfer factors and transfer coefficients were also estimated for the elements of similar chemical groups of ^{137}Cs and Sr, such as, potassium and calcium to investigate the influence of these chemically similar elements on the transfer factors and transfer coefficients of Cs and Sr isotopes. The influence of physico-chemical parameters of soil on the transfer of radionuclides and stable elements from soil to grass were also studied in detail.

In order to estimate the dose to the population around the nuclear power plant it is essential to have precise database on dietary practices and daily intake of food. Hence, a detailed demography survey was carried out around the Kaiga region. A total of 106 household were covered under the study from 12 villages around Kaiga. Database which is essential for the estimation of radiation dose and planning emergency preparedness was generated. The data collected include data on households having cows, daily intake of grass, water and cake by cow, average consumption of both cow and packed milk by the children and adults, milk yield of cows, buffalos and goats etc. On the basis of demographic survey data the annual ingestion dose to general population was estimated for different sources of milk (domestic cows and from dairy farm cows).

In order to simulate accidental release of radioactivity and to estimate the grass to milk transfer coefficients for emergency situation spike experiments were carried out. For this grass was cut and spiked with very low concentrations of stable Cs and Sr and fed to the adopted cows. The milk samples were then collected at different intervals and

analyzed and the transfer coefficients were estimated. These results are also presented and discussed in this chapter.

The subject matter of the thesis has been divided into four chapters. The contents of these chapters are briefly outlined below,

Chapter 1. Introduction and Literature Survey

This chapter presents an introduction to the subject and importance of the present studies. It also discusses about the processes by which the fall-out radionuclides reach humans through different terrestrial food pathways and the necessity of establishing site-specific transfer factors around a nuclear power plant. The chapter also presents an extensive literatures survey on the transfer factors and transfer coefficients of Cesium and Strontium in soil-grass-milk-man pathway. Important papers published in this field from worldwide particularly after Chernobyl nuclear accident in 1986 is reviewed in this chapter. Studies conducted for other nuclear power plants of India are also reviewed. The aims and objectives of the present study are presented and discussed in this chapter.

Chapter 2. Material and Methods

This chapter presents the details of topographical and geological features of Kaiga region. The methodology adopted for developing the experiment grass field, selection of sampling sites, collection and processing of samples prior to the analysis, determination of physico-chemical parameters of soil (soil texture, pH, particle size, moisture content, organic matter content, cation exchange capacity and conductivity) are presented. The analytical techniques employed for the determination of radionuclide and stable elements are presented. The details of HPGe gamma spectrometers[6] (used for the measurements of radionuclide concentrations) and the flame and graphite furnace type Atomic Absorption

[6] Karunakara, N., Somashekarappa, H. M., Narayana, Siddappa, K. ^{226}Ra, ^{40}K and ^{7}Be activity concentrations in plants in the environment of Kaiga, India. *Journal of Environmental Radioactivity*; 65 (2003), 255–266.

Spectrometer systems[7] (used for measurement of stable elements concentrations) are also presented. The calibration of the instruments, standardization of methods and quality assurance exercise (inter-comparison measurements) are also presented in detail in this chapter.

Chapter 3. Results and Discussions

This chapter provides a comprehensive discussion on the results obtained in the present study. The results on radionuclide activities (^{137}Cs and ^{40}K) and stable elements (Sr, Ca, K and Cs) concentrations in soil and grass samples collected from experimental grass field, common grazing areas and the dairy farm are presented. The results of radionuclide and stable elements concentration are analyzed with appropriate statistical tools. Frequency distribution of radionuclide and stable elements concentration in various matrices are presented. The chapter also discusses the results of statistical analysis of more than 600 transfer factor values and 340 transfer coefficient values for different radionuclides, for the soil-grass-milk pathway. The variations in radionuclide activity concentration values for different seasons of the year are presented and discussed in detail in this chapter. The results obtained for experimental grass field, common grazing areas and dairy farm are compared and appropriate inferences are drawn. The results are also compared with those reported in literatures for other parts of India and worldwide representative values reported in (IAEA-TRS-472)[8].

In order to assess the ingestion dose to members of the public due to intake of radionuclides through milk, thorough knowledge on various sources of milk and its intake rate by local public are very much essential. And for this, an extensive demographic survey was carried out around the Kaiga region. Under the demographic survey, data on dietary habits of children and adults of Kaiga region, average milk consumption by them, average milk yield rates of cows of Kaiga region and daily intake

[7] Akhaya Kumar Patra, S. S. Wagh, A. K. Jain, A. G. Hegde. Assessment of daily intake of trace elements by Kakrapar adult population through ingestion pathway. *Journal of Environmental Monitoring Assessment* 169, (2010), 267–272.

[8]. TRS-472, IAEA, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, IAEA (2010).

of fodder and cake by the cows were collected. The results of demographic survey are also presented and their use in estimating the dose is explained. The results of dose estimation due to the ingestion of cesium and strontium through milk consumed from the dairy farm and that from domestic cows of Kaiga region are presented. From the analyses of the data and discussions appropriate conclusions are drawn which are presented in the next chapter.

Chapter 4. Summery and Conclusion

This chapter presents the summery and important conclusions drawn from the present study. This includes the brief summary of activity concentrations of radionuclides and concentration of stable elements in soil, grass and milk samples collected around the Kaiga region. Important findings on the estimation of the soil to grass transfer factors and grass to milk transfer coefficients for ^{137}Cs, stable Cs, Sr, ^{40}K and Ca are presented. Conclusions drawn from the spike-experiment results are also presented at the end of this chapter.

Some of the important conclusions of the study are:

- Activity concentration of ^{137}Cs, ^{40}K and concentration of stable Sr, and Cs in soil varied in the ranges 1.1-25.7 Bq kg^{-1}, 68.1-861.1 Bq kg^{-1}, 0.14-64.3 mg kg^{-1} and <0.28-13.0 mg kg^{-1} respectively.

- Activity concentration of ^{137}Cs, ^{40}K, and concentration of stable Sr, and Cs in grass varied in the ranges <0.05-5.3 Bq kg^{-1}, 133.4-3351 Bq kg^{-1}, 2.7-88 mg kg^{-1} and <0.04-2.2 mg kg^{-1} respectively.

- Activity concentration of ^{137}Cs, ^{40}K, and concentration of stable Sr, and Cs in milk varied in the ranges <0.01-0.66 Bq L^{-1}, 34.6-145.8 Bq L^{-1}, 0.11-1.0 mg L^{-1} and <0.002-0.28 mg L^{-1} respectively.

- Soil to grass transfer factor values of ^{137}Cs and ^{40}K varied in the range 3.0×10^{-2}-6.4×10^{-1} and 0.39 to 24.5 respectively with corresponding mean values of 1.3×10^{-1} and 6.9 respectively.

- The soil to grass transfer factor values of ^{137}Cs obtained for experimental field are comparable with that observed for common grazing areas and other regions of India but are found to be an order of magnitude higher when compared to the IAEA values.

- The discrimination factor values between ^{137}Cs and ^{40}K for grass grown in experimental field, common grazing areas and the dairy farm field had mean values of 0.05, 0.04 and 0.008 respectively. Similarly the discrimination factor values between stable Cs and stable K had a mean value of 0.24 for experimental grass field and 0.15 for common grazing areas.

- The soil to grass transfer factor values of stable strontium varied in the range 0.18-8.6 mean value of 2.4.

- The daily intakes of grass by local breed cows were significantly lower than the value given in IAEA-TRS-472.

- The grass to milk transfer coefficients of ^{137}Cs for the Kaiga region varied in the range 3.3×10^{-3} - 1.0×10^{-1} d L^{-1}. The grass to milk transfer coefficients of ^{137}Cs for adopted cows were very much comparable to the cows of local farmers whereas it is observed to be an order of magnitude higher than that observed for dairy farm cows and also to the value reported for other India environment and the values complied in IAEA (2010) report.

- The reasons for the higher transfer coefficient observed for adopted cows and cows of local farmers is due to the use of actual measured value of daily dry matter intake by cows. If transfer coefficient values are calculated considering the

dry matter intake as 16 kg d^{-1} as suggested in IAEA (2010) then the mean values of transfer coefficients for ^{137}Cs for the adopted cows, local cows of farmers and that of dairy cows are very much comparable to each other and also with many of the reported values.

- Further, the adopted cows and local cows graze in the grass fields themselves where as cows in dairy farm are fed in the shed. It may also be expected that for the cow which graze in the field transfer coefficient values may be higher due to possible ingestion of soil along with grass.

- It is reported for animals even of the same species to exhibit pronounced differences in metabolism due to factors like growth rate and lactation (Skuterud *et al.* 2005). Also, the milk yields of adopted cows and the local cows were significantly less but highly dense when compared to the dairy cows and this could be another possible reason for observed order of magnitude difference in transfer coefficient values.

- The ^{137}Cs concentration ratio (CR) for adopted cows, local cows of Kaiga and dairy cows were found to have mean values of 0.15, 0.13 and 0.04 respectively. This ratio for stable cesium for adopted and local cows were found to be equal to 0.1 and 0.11 respectively.

- The mean value of grass to milk transfer coefficients for strontium was found to be 4.6×10^{-3} d L^{-1} which is comparable to the worldwide representative value given IAEA (2010).

- The mean value of Sr grass to milk concentration ratios for adopted cows and local cows of Kaiga were 0.018 kg L^{-1} and 0.02 kg L^{-1} respectively. Similarly, mean values of Ca grass to milk concentration ratios for adopted cows, local cows of Kaiga and dairy cows were 0.18 kg L^{-1}, 0.18 kg L^{-1} and 0.058 kg L^{-1} respectively.

- The strontium-calcium observed ratio (OR) values for adopted cows and local cows were 0.1 and 0.13 respectively. These values are comparable with the literature values, which vary in the range 0.03-0.40.

- Cow is the important domestic animal in Kaiga region. Out of 106 households 52 households have a total of 195 cows out of which 189 is yielding milk.

- Milk yield from local cows is surprisingly very low and average milk yield from cow is 0.3 L d^{-1}.

- The average milk consumption by a child and adult is 0.22 L d^{-1} and 0.27 L d^{-1} respectively.

- The internal dose due to ingestion of ^{137}Cs through milk of local cows by child and adult of Kaiga are found to be 0.29 µSv y^{-1} and 0.39 µSv y^{-1} respectively. Similarly, the doses due to the ingestion of ^{90}Sr were found to be 0.0018 µSv y^{-1} and 0.00081 µSv y^{-1} for child and adult of Kaiga region respectively. It should be note that the ^{90}Sr activity concentration was below detection levels in milk. However, for the estimation of ingestion dose we have considered the milk

activity concentration as 0.003 Bq L^{-1}, which is the minimum detection level of activity concentration of this radionuclide.

- The Cs and Sr transfer coefficient values obtained from spike experiments were found to vary in the range 8.3×10^{-4}-1.3×10^{-2} and 8.2×10^{-4} - 2.0×10^{-3} d L^{-1} respectively with corresponding mean values of 4.4×10^{-3} d L^{-1} and 1.4×10^{-3} d L^{-1}.

- The mean value of transfer coefficients obtained from spike experiments for Cs was an order of magnitude lower than that observed for equilibrium coefficient. Transfer coefficient value observed from spike experiments for Sr was of the same order of magnitude as that of equilibrium conditions.

Annexure

It may be noted that only the summary of the results are presented in chapter 3. This section provides the detailed results of activity concentration, transfer factors and transfer coefficients of samples collected from experimental grass field, common grazing areas and the dairy farm in the form of total 48 tables. The results presented can be broadly classified as:

i. Radionuclides (^{137}Cs and ^{40}K) and stable elements (Sr, Ca, K and Cs) activity concentrations in soil, grass and soil to grass transfer factors for experimental grass field, common grazing areas and the dairy farm grass field (16 tables).

ii. Radionuclides (^{137}Cs and ^{40}K) and stable elements (Sr, Ca, K and Cs) activity concentrations in milk and grass to milk transfer coefficients for adopted cows, local cows and dairy cows (16 tables).

iii. Results of demographic survey in the Kaiga region (11 tables).

iv. Results of estimation of grass to milk transfer coefficients for emergency situations (5 tables).

6.0 Research Publications in Journals, National and International Conferences related to the thesis work

(i) Journals

1. Estimation of grass to milk transfer coefficient for Cesium for emergency situations.
   Ujwal P, Karunakara N, Yashodhara I, Dileep B N and Ravi P. M., 2012. Journal of Radiation Protection and Environment, in press.

2. Studies on soil to grass transfer factor (F_v) and grass to milk transfer coefficient (F_m) for Cesium in Kaiga region.
   Karunakara, N., Ujwal, P., Yashodhara, I., Chetan Rao, Sudeep Kumara, Dileep, B.N., Ravi, P.M. (Submitted to Journal of Environmental Radioactivity).

3. Studies on soil to grass transfer factor (F_v) and grass to milk transfer coefficient (F_m) for Strontium in Kaiga region.
   Karunakara, N., Ujwal, P., Yashodhara, I., Chetan Rao, Sudeep Kumara, Dileep, B.N., Ravi, P.M. Manuscript under preparation for submission to Journal of Health Physics, USA.

4. A comparative study on grass to milk transfer coefficients for equilibrium and emergency situations. Manuscript under preparation for Journal of Radiation Measurements.

(ii) National and international conferences

5 Estimation of grass to milk transfer coefficient for Cesium for emergency situations.
Ujwal P, Karunakara N, Yashodhara I, Dileep B N and Ravi P. M.
Book of Abstract. 30th IARP Conference on Radiological Protection and Safety in Nuclear Reactors and Radiation Installation. March 15-17, 2012, Mangalore University, India. (Oral presentation).

6 Studies on soil to grass to cow milk transfer of ^{137}Cs in Kaiga region.
Ujwal P, Karunakara, N., Yashodhara, I., Chetan Rao, Dileep, B.N., Ravi, P.M.
Book of Abstract. 30th IARP Conference on Radiological Protection and Safety in Nuclear Reactors and Radiation Installation. March 15-17, 2012, Mangalore University, India. (Oral presentation).

7 Estimation of grass to milk transfer coefficient for Strontium for emergency situations.
Ujwal P, Karunakara N, Yashodhara I, Sudeep Kumara, Dileep B N and Ravi P. M.
National Symposium on Radiation Physics, Chennai, September 27-29, 2012 (Accepted for oral presentation).

8 Studies on soil-grass-cow-milk transfer of Strontium in Kaiga region.
Ujwal P, Karunakara N, Yashodhara I, Chetan Rao, Dileep, B.N., Ravi, P.M.
National Symposium on Radiation Physics, Chennai, September 27-29, 2012 (Accepted for oral presentation).

(iii)Publications on related work

9 Site-specific Transfer factors ^{226}Ra, ^{228}Ra, ^{40}K, and ^{137}Cs for vegetables in Kaiga region.
Chetan Rao, P.Ujwal, N.Karunakara, H.M.Somashekarappa, P.D.Nayak and P.M.Ravi.
Journal of Radiation Protection and Environment, 31, 453-455(2008).

10 Soil to Paddy transfer factors of ^{40}K, and ^{137}Cs for Kaiga region".
Chetan Rao, Ujwal Prabhu, I.Yashodhara, N. Karunakara, PD Nayak and P.M.Ravi.
18th National Symposium on Radiation Physics, Udaipur, Nov 19-21, G20, 165, (2009).

11 A comparative study on radionuclide concentrations in forest and farmland soils around Kaiga region.
Chetan Rao, Ujwal P, Yashodhara I, Karunakar N, Somashekarappa H.M, Nayak P.D, Ravi P.M.
National Conference on Accelerator and Low Level Radiation Safety, New Delhi, Nov 18-20, PP51, 100, (2009).

12 ^{7}Be and ^{210}Pb in air and plants in the environs of Kaiga Nuclear Power Station.
N.Karunakara, I. Yashodhara, P.Ujwal, Chetan Rao, H.M.Somashekarappa, P.M.Ravi.
National Conference on Accelerator and Low Level Radiation Safety, New Delhi, Nov 18-20, PP53, 102, (2009).

13 ^{210}Pb, ^{7}Be and ^{137}Cs in rice and vegetables.
N. Karunakara, Chetan Rao, I Yashodhara, P.Ujwal and P.M.Ravi. International Tropical Conference on Po and Radioactive lead isotopes, Seville, Spain, Oct 26-28, 25A, 113, (2009).

14 Natural Radioactivity in Udupi and Karkala Taluks of Coastal Karnataka. Gerald P, N.Karunakara, H.M.Somashekarappa, Chetan Rao, Ujwal Prabhu and I Yashodhara.
Indian Journal of Pure and Applied Physics. 40, 527-529 (2010).

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